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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

**APPLICATION OF LASER TECHNOLOGY
TO GEODETIC MEASUREMENTS AND MAPPING**

A Technical Summary Report

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1.0 INTRODUCTION

The objective of this report is to summarize the results of a study-review which was conducted on published technical information on laser altimeters and rangefinders. The report includes observations and discussions with some experts in the field obtained during a few, but selected, visits to industrial organizations which have been noted contributors to the advancement of laser technology, in particular, to the development of the laser altimeter-rangefinder.

This effort was undertaken to update the available background information on laser altimeter-rangefinder techniques and new approaches, and to establish the foundation of the technical competency in this area in the Optical Systems and Components Branch, Optics Laboratory of the Electronics Research Center (ERC).

The projected in-house efforts and the anticipated outside ERC-supported research and development work in these fast-advancing laser technology application areas will complement the already established laser research and development work being done in ERC's Optics Laboratory.

Section 2.0 of the report presents the conclusions which resulted from this study and associated reviews and discussions. Section 3.0 presents the writer's short-range recommendations. Section 4.0 describes and discusses the commercially available laser rangefinder-altimeter systems (4.1), systems presently under development (4.2), and some advanced concepts and techniques (4.3). Section 5.0 presents directly related references.

2.0 SUMMARY AND CONCLUSIONS

This section presents the results of a preliminary review of the laser rangefinder and altimeter technology. It is not necessarily all-inclusive, but it represents the initial attempt to acquire the basic understanding of the present state and the direction of the laser rangefinder-altimeter technology and its applicability to geodetic measurements and mapping. This type of review will continue and will be updated more or less periodically.

The review revealed that several ground-based and airborne ranging-altimeter systems are offered commercially by several industrial organizations (Spectra-Physics, Korad, Hughes). All these systems are intended for ranges up to 50 kilometers at favorable atmospheric conditions with a range accuracy of ± 10 feet.

Several longer range systems are presently under development, but only one (TRG/MSFC) is intended and designed as a spaceborne laser altimeter for cooperative operation with photographic lunar mapping and Earth resources surveying cameras. The development of this altimeter is in the initial pre-prototype phase. It appears that at least 2 more years of intensified development work will be required in order to deliver a qualified flight altimeter system with 80- to 100-km lunar- and 460-km Earth-oriented ranging capability.

It was concluded that since the invention of the ruby laser by T. H. Maiman^{1,2} in 1960, the widest and the most practical application of the new technology had been in ranging and altimetry. Present laser technology is already capable of providing a wide selection of different power level and other major characteristic solid-state,^{3,4} gas,⁵ and injection lasers⁶ for future ranging and altimetry requirements. Basic and applied laser research and development efforts are continuing throughout the industry at a high level. It is concluded that no additional support or encouragement are required in this area at the present time.

The review of the literature and the discussions with the workers in the laser rangefinder and altimeter field indicated that not enough attention is being directed to spaceborne system environmental qualification requirements and problems. If not corrected, this situation may bring about the repetition of the bitter qualification experience of the early spaceborne operational systems for the TIROS, RANGER, and NIMBUS projects. Very much time, effort, and money will be saved later if early consultations are held and the past environmental qualification experience is transferred to the laser altimeter design and development efforts before the finalization of the flight prototype designs. A new group of workers has entered laser technology research without any first-hand experience in spaceborne system design and environmental qualification requirements and problems. There exists a need for immediate support and additional efforts in the new laser technology field.

Several ground-based laser tracking and ranging systems exist or are being developed. A few of these systems have been operational for some time. Also some international capability exists in this area. The French, in particular, have accumulated optical satellite ranging and tracking information from two stations near San Michel, France and San Fernando, Spain. It is known that the Russians have done some satellite ranging, but not much more is known about it. Most of the results have been published.

Studies and the generation of design specifications are being planned by NASA Headquarters (SAG) for mobile (transportable) laser tracking and ranging stations which could meet the requirements of making operational geodetic measurements from remote sites. The Optical Systems and Components Branch of the Optics Laboratory, ERC, is interested and ready to participate in this area of tasks.

A small service contract (\$2.5K) has been let to ADCOM, a division of Teledyne, Inc., Cambridge, Mass., under the title: "Design Criteria for Radar Tracking." The emphasis of this effort will be an analytical evaluation of (1) fundamental theories, and (2) design and performance of practical systems. This review will be published as an addendum to this report.

Additions to this report will be submitted as new technology and/or results become available.

3.0 RECOMMENDATIONS

On the basis of this study and review, and for the purpose of identifying the technical areas which need additional support and attention so that the advancement of the laser rangefinder-altimeter technology would be well coordinated and balanced, the following recommendations are made:

1. Increased support and in-house technical efforts should be directed towards the space environmental qualification of various applicable laser sources. Preferably, this should be accomplished before the final design of a spaceborne altimeter system.
2. Ways and means of transferring without delay the available past experience of spaceborne operational system design criteria and the environmental design requirements to the laser altimeter technology should be sought.
3. New and more accurate laser ranging and altimeter technique development should be supported and encouraged, particularly in the return signal detection and processing areas.

4.0 DISCUSSION

One of the first, and still the major, application areas of the laser is that of rangefinding and altimetry. To date, a number of laser rangefinders have been designed and fabricated by both military and industrial organizations for application to ground and airborne surveillance, target acquisition, and fire control systems. Most of these rangefinders have utilized a Q-switched ruby laser as a transmitter. However, some of the most recent systems are using neodymium as the laser element, and it is anticipated that this trend will continue in the future.

A preliminary review of industrial and Government organizations which are active in the laser development and application work indicate that a significant effort is being devoted to laser altimeters and rangefinders. Some 17 organizations were identified as having performed design studies, built experimental and operational systems, and performed measurements on ground, sea, and from air. Table I lists these organizations.

In addition to organizations listed in Table I, a few Government installations and Government-supported organizations have established laser satellite and/or lunar tracking and ranging capabilities. Except for the Frankford Arsenal, which develops and builds its own laser sources, almost all other Government laboratories and installations have had their laser systems developed and installed by experienced industrial organizations. The most completely equipped and instrumented locations are: AFCRL, Bedford, Mass., NASA/GSFC, Greenbelt, Md., JPL, Pasadena, California, NBS, Boulder, Colo., and the Smithsonian Institution Astrophysical Observatory, Cambridge, Mass. The latter operates three laser tracking stations on Mt. Hopkins, Arizona, Mt. Haleakala, Maui, Hawaii, and in Dionysos, outside Athens, Greece.

4.1 AVAILABLE LASER RANGEFINDER-ALTIMETER SYSTEMS

Because of the increasing scope of laser applications for distance measurement and terrain-profile recording, industrial organizations are making available commercial laser ranging systems. So far, Spectra-Physics has announced its Geodelite CW laser ranging system (\$79,000.00), and Korad, two YAG and one ruby laser systems, which will be described in more detail in the following subsections:

4.1.1 Korad YAG and Ruby Laser Systems

Korad's Model KLRF-23 YAG laser system is a compact, high-power, repetition-rate system designed for airborne deployment or applications where minimum size is required. The system consists of two units: the laser head assembly and power supply control unit. Its performance specifications are listed in Table II.

TABLE I

ORGANIZATIONS INVOLVED IN LASER DEVELOPMENT AND APPLICATIONS

No.	Industrial Organization	Area of Participation		
		Study	Hardware Devel.	Experimental
1.	Avco	X		
2.	Boeing	X		X
3.	Douglas	X		X
4.	EG&G	X	X	X
5.	General Electric	X	X	X
6.	Hughes	X	X	X
7.	I.B.M.	X	X	
8.	Korad	X	X	
9.	Lockheed	X		
10.	Lear Siegler	X	X	X
11.	North American	X	X	X
12.	Perkin-Elmer	X	X	
13.	Raytheon	X	X	X
14.	R.C.A.	X	X	X
15.	Spectra-Physics	X	X	X
16.	TRG	X	X	X
17.	Sylvania	X	X	X

TABLE II

PERFORMANCE SPECIFICATIONS
KORAD MODEL KLRF-23 YAG LASER SYSTEM

<u>Laser Material</u>	<u>Neodymium-Doped YAG</u>
Wavelength	1.06 μ
Range	>20,000 m
Range Resolution	± 10 feet
Beam Divergence	4 mrad (uncorr.)
Output Power	8-10 MW
Pulse Width	8-10 nsec
P.R.F.	10 pps
Pulse Energy	≥ 80 MJ
Q-Switch	Pockel Cell
Input Power	28 V-dc, 20 A
Weight: Laser Head	10 lb
Power Supply	12 lb

Ground-operated laser rangefinder performance specifications are listed in Table III.

4.1.2 Spectra-Physics Geodolite

The Spectra-Physics Geodolite system is the result of 4 years of development work on a modulated CW laser distance-measuring instrument. The Geodolite 3G system has been proven by field measurements. High resolution profiles of the surface of the Earth and the ocean waves have been recorded from an altitude of 15,000 feet. The published Model 3G performance specifications are shown in Table IV.

4.2 DEVELOPMENTAL LASER RANGEFINDER-ALTIMETER SYSTEMS

The General Electric Company has developed a small and relatively inexpensive (\$95.00) pulsed gallium arsenide injection laser range-finder system for use as an automobile safety device. It can warn the driver of a car when the distance between his car and the car immediately ahead of him becomes less than a predetermined value. This laser safety system could also operate the brakes of the car automatically. The General Electric Company has demonstrated this system to the Chrysler Corporation and the General Motors Corporation. It is known that Ford is developing a similar laser automobile safety device.

RCA has developed a gallium arsenide early warning system for application on high-speed trains. This system has been experimentally tested on an electronics testing ground near Denver, Colorado. When fully developed, this ranging system will be capable of detecting a 1 cubic inch obstacle on the railroad tracks from 5 miles away while traveling at 200 mi/hr.

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TABLE III

GROUND-OPERATED LASER RANGEFINDER PERFORMANCE SPECIFICATIONS		
	Model KLRF-20	Model KLRF-21
Material	Ruby	Neodymium-Doped YAG
Wavelength	6943 Å	1.06μ
Range	200-20,000 m	45-5500 m
Range Accuracy	±2.5 m	±8.5 m
Beam Divergence	1.0 mrad	1.0 mrad
Output Power	5.0 MW	1.0 MW
Pulse Width	20 nsec	20 nsec
P.R.F.	4.0 ppm	Single shot and/or continuously variable from 1 to 10 pps
Input Power	Self-contained re-chargable battery for 200 shots	28 V-dc; 350 W
Range Readout	Digital	Digital and Analog
Temp. Operating Range	-10°F to 110°F	0 to -50°C
Weight	40 lb (including batteries)	18.5 lb
Operating Life	>350,000 shots with scheduled maintenance	>1000 hr
Physical Configuration	1 Unit	2 Units

Most other present laser rangefinder-altimeter development programs are intended for military applications on the ground. Few systems are being developed for airborne applications, and still fewer for use on the sea. The major contributors to the present state of this technology have been Hughes Aircraft, Korad, TRG, Lear Siegler, and Frankford Arsenal. The requirements for the range capability of the military systems have been limited from 2 to 15 miles. The majority of them have employed a pulsed ruby laser (6943 Å).

TABLE IV

MODEL 3G SYSTEM PERFORMANCE SPECIFICATIONS	
Laser	He-Ne
Wavelength	6328 Å
Power-Output	100 mW
Range (in clear air)	50 miles at night 20 miles in full sun
Oscillator Stability	1 in 10^8 per day; 1 in 10^6 per year
Mounting	Alti-azimuth mount with horizontal and vertical tangent screws; graduated vertical and horizontal circles with verniers reading to 1 minute.
Dimensions (overall) and Weight	Telescope Assembly: 34x20x16 in., 100 lb Control Unit: 17x16x5-1/4 in., 40 lb Digital Readout: 17x21x5-1/4 in., 33 lb
Ambient Temperature	Operating: -20°F to 120°F
Input Power	115 ±10 V, 50 to 400 Hz, 400 VA

Presently, three known unclassified developmental programs are in progress. Two are intended for space application, and the third for ranging to the moon from Earth. These programs are discussed in more detail below.

4.2.1 Lunar Mapping Altimeter (MSFC/TRG)

Preceding the present hardware development program at TRG, NASA/MSFC sponsored a study and design specification program on spaceborne laser altimeter systems with the Raytheon Company, Space and Instrumentation Systems Division, Sudbury, Mass. The work was performed

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from September 1966 to January 1967 under contract NAS 8-21013.⁷ The results of this study showed that a laser altimeter could be developed to meet the space mission requirements for photogrammetry and geodesy.

Based upon the analysis conducted and a decision to utilize presently available laser transmitters, a ruby laser system operating at 6943 Å was recommended to perform the Earth-orbiting mission over land and sea. For lunar operation a neodymium-doped YAG laser system operating at 10,600 Å was recommended. This decision was predicated upon the lower power, lower weight, and smaller volume requirements of the YAG-type system as compared to the ruby.

The subsequent hardware development contract was awarded to TRG. The goal of the present program is to develop a flight pre-prototype laser altimeter system which will be tested in an aircraft.

A design review was conducted on March 11, 1968, at TRG. The Optics Laboratory participated with two observers. The major subject was the discussion and approval of the redesigned optics. An on-axis optical system was proposed in order to meet the size and performance specifications.

The TRG/MSFC laser altimeter specifications are outlined in Table V.

TABLE V

TRG/MSFC LASER ALTIMETER SPECIFICATIONS	
Wavelength	6943 Å
Energy	0.140 J
Beam Angle	40 μrad
Pulse Repetition Rate	6 (per min)
Pulse Width	20 nsec
Range Accuracy	±2.5 m
Orbit Altitude	460 km
Illuminated Area on-Ground	18 ft dia.
Mounting	Fixed--boresighted with metric camera
Spacecraft Stability	±1/2 deg

The delivery of the pre-prototype lunar altimeter system is anticipated in October, 1968.

4.2.2 Optical Spacecraft Ranging and Automatic Docking System (MSFC/ITT)⁸

A guidance system for rendezvous and docking, using gallium-arsenide injection lasers and a gallium-arsenide spontaneous source, has been developed for NASA/MSFC by ITT Laboratory, San Fernando, Calif. It is intended for use in either manned or unmanned spacecraft to provide the necessary intelligence to the guidance computer to effect a complete rendezvous and docking operation automatically. This system is the culmination of 4 years of study, experimentation, and hardware development.

The system uses uncooled gallium-arsenide laser arrays operating in a pulsed mode for initial acquisition and subsequent measurement of X and Y angles, angle rates, range, and range rates. When the distance between the two spacecraft has been reduced to less than 3 km, greatly increased range and range rate accuracy are obtained by the use of an incoherent gallium-arsenide diode source continuously modulated at a high frequency, and using phase-locked detection techniques in the receiver. Control of the spacecraft from this sensor continues until the docking operation is completed.

In its present configuration, the laser guidance system utilizes equipment on both spacecraft, which are designated the chaser vehicle and the target vehicle. Normally, the target vehicle will remain in a fixed orbit, while the chaser vehicle will use attitude control as necessary to maintain the proper orientation for the chaser vehicle approach.

The sensing element in the receiver is an image-dissecting multiplier phototube with an S-1 photo-emissive surface, which has its peak spectral sensitivity at approximately 9000 Å. A narrow band interference filter in the optical path is used to minimize interference from the sunlit background.

The system specifications are summarized in Table VI. This spaceborne laser guidance system has been successfully tested and operated in a space simulator at the Martin Company, Denver, Colorado, facility.

4.2.3 Lunar Tracking System (AFCRL/Hughes)⁹

A feasibility study of laser-ranging systems working from an Earth-based astronomical observatory against an optical retroreflector placed on the moon by a spacecraft or an astronaut was performed by Hughes Aircraft Company, Culver City, California, from April, 1965, to April, 1966. It was concluded that, from consideration of the restraints imposed by present technology and the optics and kinematics of the Earth-moon system, a 10-joule, 10-nsec, Q-switched ruby laser with photomultiplier receiver, both operating through a single, 60-inch telescope, might be selected for the system design.

TABLE VI

SYSTEM SPECIFICATIONS FOR GaAs LASER	
Wavelength	9000 Å
Power: Peak Pulsed	1000 W
Average (m Watts)	200 mW
Pulse Width	100 nsec
Pulse Repetition Rate	2000 (per sec)
Range--Pulsed	120 km
Range--CW	3 km
Range Accuracy 120 to 3 km	1/2 percent
Range Accuracy 3 to 0 km	10 cm
Angle Accuracy	10 arc sec
Size	1 ft ³
Weight	35 lb
Power--Input	15 W

The analytical evaluation of such a system showed that it would be capable of measuring range with a precision of a few meters at all hour angles and at almost all phases of the moon.

Information obtained by laser ranging between an Earth station and points on the moon will be valuable to several scientific disciplines, including geodesy, and celestial mechanics. Important results which are likely to come from a systematic program of lunar laser ranging include improved knowledge of the size of the moon and its orbit, determination of the gross figure of the moon with more assurance than it is now known, greatly improved libration data, and accurate Earth station coordinates that are independent of geodetic surveys.

While the above study was still in progress, AFCRL contracted for the construction of a telescope with a 60-inch diameter aperture, to be installed in the Catalina mountains of Arizona at a site maintained by the Lunar and Planetary Laboratory of the University of Arizona. The laser system has been designed around the above telescope, and for a specific experiment. For this reason, commercially available equipment has been used whenever possible in preference to special signs which might be slightly more effective but more expensive and less flexible.

Table VII summarizes the parameters of the systems for range-finding and for photographing the retroreflectors with the separate 60-inch photographic telescope.

At the time of this report, the 60-inch telescope has been delivered to the Arizona site and the mount installed. The ruby laser system is being built by the Hughes Aircraft Company and will be completed by the end of this year (1968). The installation and debugging

TABLE VII

SUMMARY OF DESIGN PARAMETERS		
	Ranging	Photography
Ruby Laser	Q-switched	Ordinary
Ruby Diameter and Length	15 mm x 15 cm	15 mm x 15 cm
Laser Output Energy	10 J	40 J
Pulse Duration	10^{-8} sec	4×10^{-4} sec
Laser Output Power	10^9 W	10^5 W
Laser Beam Divergence	0.3 - 1.0 mrad	0.3 - 1.0 mrad
Repetition Period (minimum)	5 sec	5 sec
Average Laser Output Power	2 W	8 W
Telescope Diameter	1.5 m	1.5 m
Optical Efficiency on Transmit	0.75	0.75
Receiver Bandwidth	10 Å	10-100 Å
Optical Efficiency on Receive	0.4	0.4
Detector Quantum Efficiency	0.1	-
Travel Time Counter Rate	100 mc	-
Pump Energy	10^4 J	10^4 J
Average Power into Laser Head	2 kW	2 kW
Operating Power	5.6 kW	5.6 kW
Weight of Telescope--Mounted Unit	100 kg	100 kg

of the lunar ranging system is scheduled for another year. The experiments are planned to start in 1970.

4.3 ADVANCED TECHNIQUES AND CONCEPTS

As mentioned earlier in this report, the newly emerging laser technology found its first major application in optical ranging systems. In the meantime, the research and advanced development efforts have been devoted towards the increased range and range accuracy capabilities. The ultimate range accuracy of the measurement is determined by the accuracy of the measurement of light speed. All practical and reliable laser distance measuring systems are still far from this final limitation. The atmospheric variations, the laser output variations, the detector sensitivity and response time limitations and the received signal processing capabilities are still the major limiting factors in the range accuracy measurements.

The workers in this field are searching for and developing new and improved optical ranging and altimetry techniques. Some of them will be discussed in the following subsections. Most of these techniques are intended for CW operation, and, therefore, are applicable only to systems for shorter range determination. The output power capability of CW lasers is rapidly increasing, and these advanced techniques will become important alternatives. However, wide application of high power CW lasers for ranging and altimetry will not be practical because of the inefficient use of the radiated power.

4.3.1 FM-Subcarrier Laser Radar¹⁰

Theoretically, a CW optical ranging system employing coherent optical transmission and heterodyne reception, provides exceptional range and velocity resolution. However, because of the very small wavelength of the optical radiation employed, numerous practical difficulties arise when heterodyne detection is attempted. First, acceptable angular misalignment of the optical system is very small; second, atmospheric turbulence causes phase distortion of the optical wavefronts; third, the Doppler shift of a high velocity target is many thousands of Hertz (Hz) and necessitates the use of a broad-band insensitive receiver.

These degrading effects can be overcome by utilizing CW laser radiation as a carrier of FM-modulated VHF, UHF, or microwave subcarriers. Frequency modulation of the subcarrier provides the means for coherent demodulation and information processing. Since the subcarrier modulation is in the radio frequency region rather than the optical region of the spectrum, the Doppler shift will be a few Hz per knot, rather than several MHz per knot.

An experimental FM subcarrier laser radar system has been constructed and tested by Douglas Aircraft Co., Inc., Missile and Space Systems Division, Santa Monica, California. Operation of the system is as follows: (1) A He-Ne laser beam is intensity-modulated by a KDP crystal driven by a frequency swept generator; (2) a portion of the diffused reflection from the target surface is collected, filtered, and then detected by a photomultiplier tube; and (3) the output signal is mixed with the frequency swept source signal to produce sum and difference frequencies.

The difference frequency, which is proportional to target range, is selected by a low pass filter, and is amplified and displayed on a frequency counter. Several experiments have been performed to assess the system performance. Range counts were made over one full cycle of the modulating waveform and were found to be invariant as long as the peak-to-peak driving voltage remained constant. This result is significant in that the frequency sweep linearity requirements for a modulator driver are substantially relaxed in this mode of operation.

The method of CW optical ranging described above has several practical advantages. It is free of the alignment difficulties and atmospheric distortion which is present in optical heterodyne detection.

It is adaptable for use with powerful CO₂ lasers, and then it is capable of measuring the ranges of hundreds of miles and range resolution of about a foot.

4.3.2 Geodetic Laser Survey System (North American)¹¹

The existing laser geodetic survey systems are restricted to a precision of several parts per million of the distance measured. The major limiting factor in all electromagnetic distance measuring techniques is the uncertainty introduced by atmospheric fluctuations which affect the value of the refractive index. The resultant variations in the velocity of light causes corresponding distortions in distance measurements. The Geodetic Laser Survey System described herein and developed by North American Aviation, Inc., subsequent to an extensive study program of Laser Space Communication Systems (LACE) under contract NAS w-977, overcomes these constraints and provides an order of magnitude improvement in accuracy. This dual-beam laser system has direct application to geodesy, earthquake prediction research, and other fields requiring precise distance measurements.

The Geodetic Laser Survey System utilizes two lasers operating at different wavelengths to obtain simultaneous, independent range measurements at two points in the optical spectrum. The light beam from each laser is modulated at a radio frequency, and the range measurement is made using this modulation frequency. By simultaneously measuring the difference in optical range or atmospheric dispersion between two optical frequencies, a factor can be determined which provides, to a first-order approximation, compensation for the temporal and spatial variation in the atmospheric index of refraction.

This approach not only eliminates the necessity for measuring atmospheric parameters at discrete points along the optical path, but allows the derivation of a true average for these atmospheric parameters. This produces an order of magnitude improvement in the precision with which long ranges can be measured.

The original experimental system is shown in a schematic configuration in Figure 1 and the modified second-generation system, presently undergoing design changes and reassembly into the mobile unit, is shown in Figure 2. Three major improvements have been made in the modified system: the laser wavelength, the detection and phase measurement techniques, and the modulating frequency.

The use of the new low-power laser at the shorter (visible) wavelength overcame the objectional below-quantum efficiency of available infrared photodetectors. In the original experimental configuration, considerable phase jitter in the 100-MHz signal was encountered during passage through the photomultipliers. The modified system uses a nominal 5-kHz frequency obtained by heterodyning at the first dynode of the photomultiplier with a signal that is phase synchronous with, and derived from, the same source as the modulating frequency. The effects of transit-time jitter is thus eliminated.

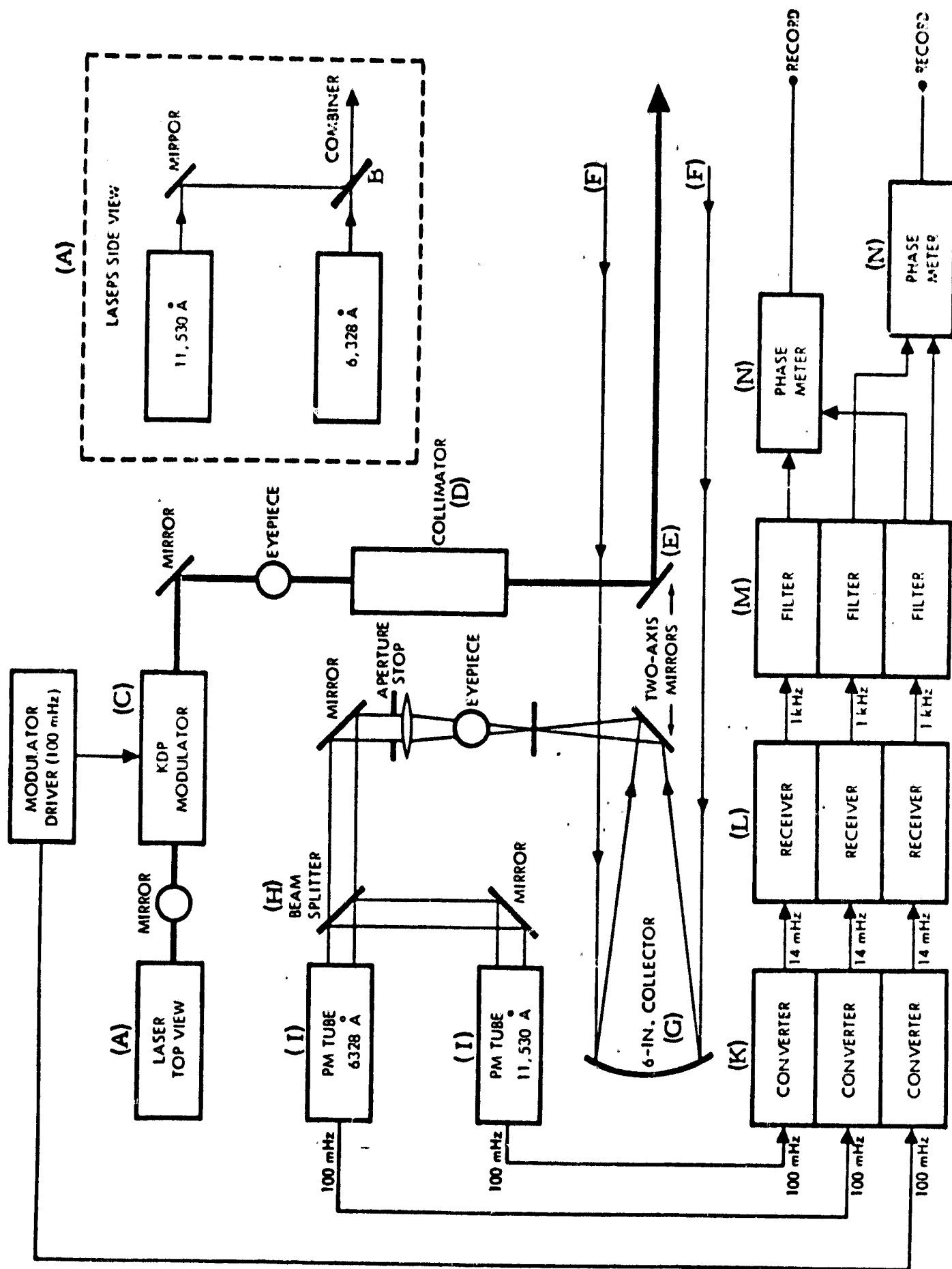


Figure 1. Block Diagram of Original System

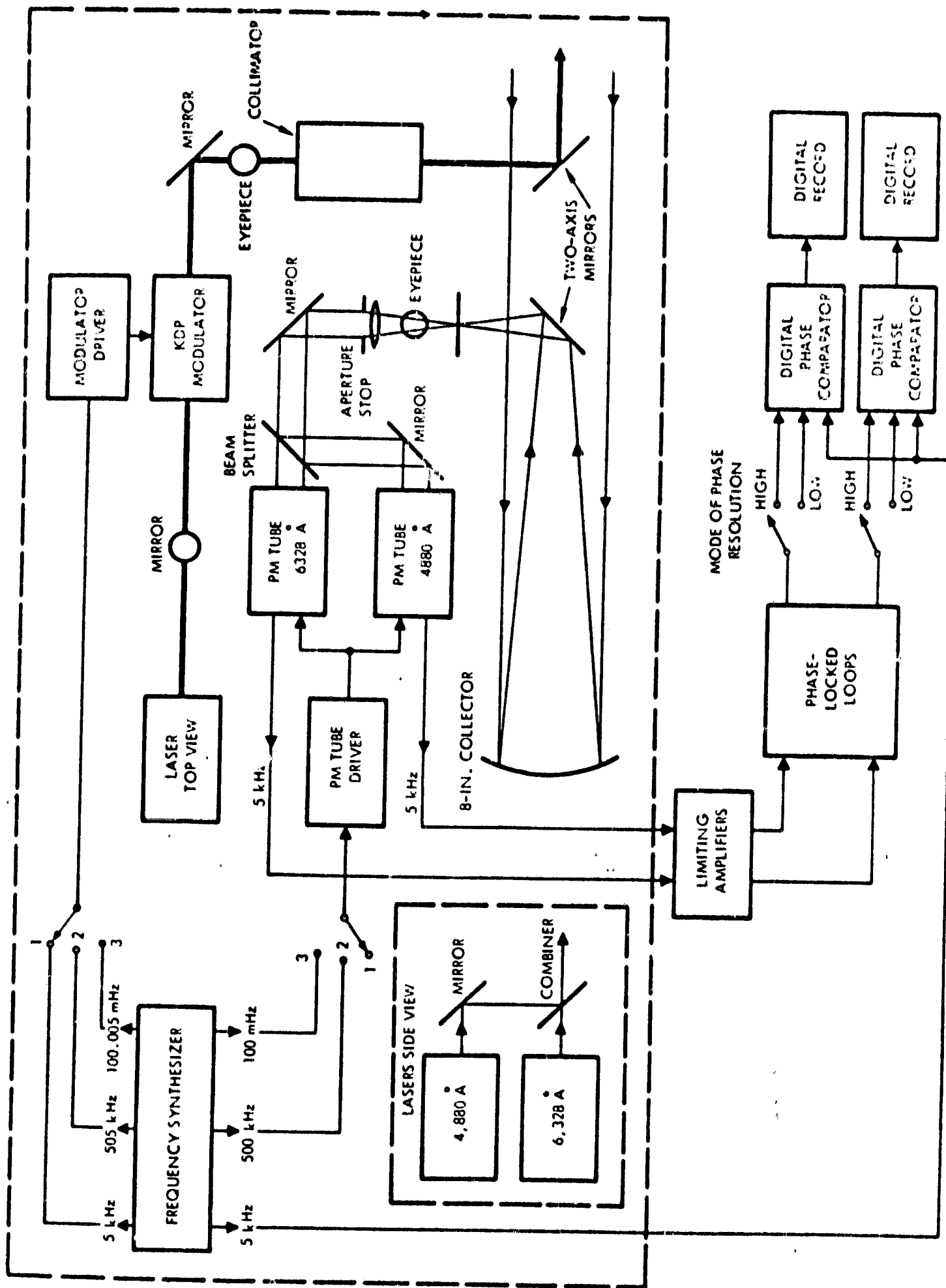


Figure 2. Modified System Block Diagram

Additional modulating frequencies have been added to permit unambiguous ranging over the total distance, and the original 100-MHz modulation frequency has been modified to reflect the constant 5-kHz intermediate frequency in the detection system. The North American group at Downey, Calif., hopes to complete these modifications in the near future, and to be back performing field measurements along the San Andreas fault system by this spring.

4.3.3 Mode-Locked Nd;YAG Laser System

The Optical Systems and Components Branch of the Optics Laboratory at NASA/ERC is procuring a short-pulse (10^{-10} sec), mode-locked Nd;YAG laser system for experiments and the development of high-accuracy, distance-measuring techniques. Three potential sources are considered: Raytheon Company, Sylvania-Western Division, and United Aircraft Corp. It is estimated that this system will cost approximately \$24 to \$29,000. All major associated instrumentation also has been ordered or selected. It is expected that the in-house experiments and evaluation of new techniques will begin within the next 6 months.

Parallel efforts have been initiated by the same Branch at ERC on space qualification of Nd;YAG laser sources. This work is supported under the OTS E programs. Related research and development work is carried on in the Optics Laboratory at ERC in optical physics, optical materials, and generation and detection of optical radiation and modulation. Therefore the laser ranging and altimetry, optical tracking, and high data rate communication system research and development work will be complementary and beneficial to the other work performed by this laboratory.

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